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3,291,704

DISTILLATION APPARATUS HAVING CORRUGATED HEAT TRANSFER SURFACES

Filed June 28, 1963

Fig. 1

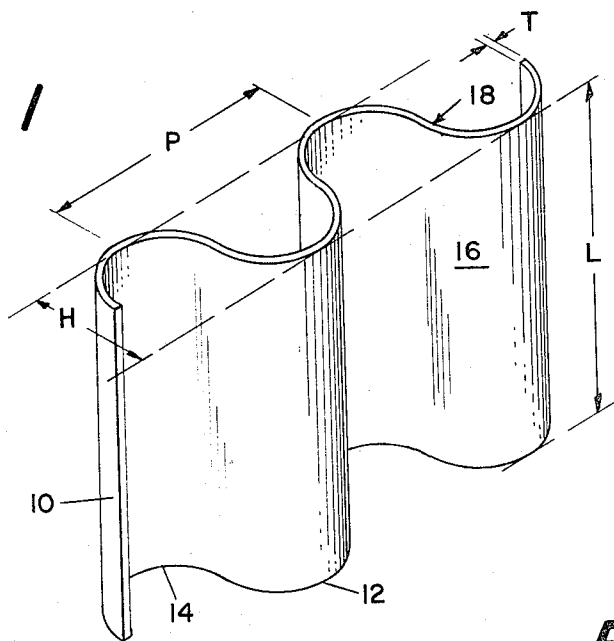


Fig. 2

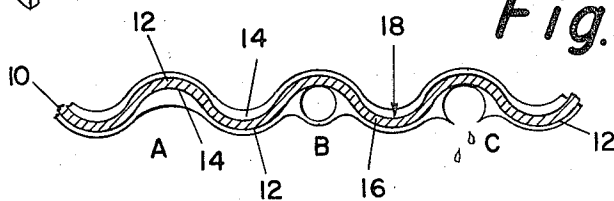


Fig. 3

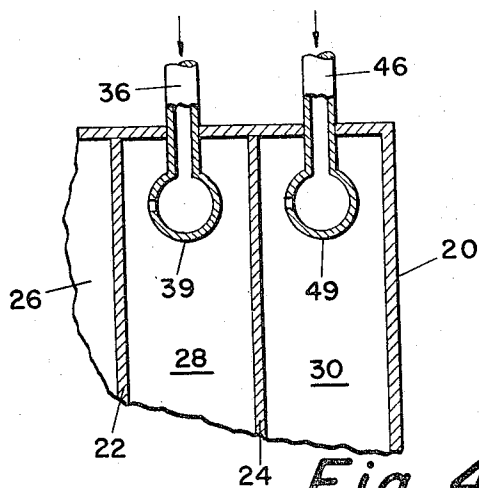
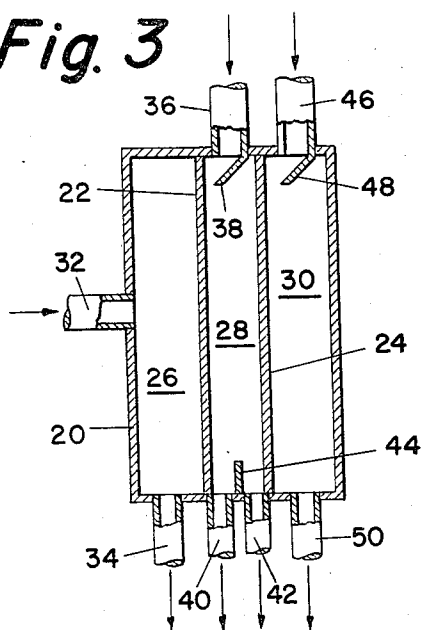


Fig. 4

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DISTILLATION APPARATUS HAVING CORRUGATED HEAT TRANSFER SURFACES

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7 Claims. (Cl. 202—236)

This application is a continuation-in-part of application Serial No. 176,711, filed March 1, 1962, and now abandoned entitled, "Distillation Apparatus," which is assigned to the assignee of this application.

This invention relates generally to distillation apparatus and more particularly to a high performance heat transfer wall to be used in saline water distillation apparatus.

Arbitrarily, water is considered to be "saline" when it contains 1000 or more parts of salt per million parts of water, while it is considered to be fresh when it has fewer than 1000 parts per million of salt. Sea water contains about 35,000 parts per million of salt.

The increasing demand for fresh water in many areas of the world has given impetus to investigations for ways of converting saline water into fresh water in an economical manner. One process for removing dissolved salts from saline water is that of distillation, which may be performed by bringing the saline water into contact with a hot surface in order to evaporate the water and leave the salt behind, and then condensing the vapors which are produced upon a cool surface in the form of fresh water.

The heat needed to produce water vapor from saline water or distilland which is in contact with one surface or side of a heat transfer wall may be supplied by stream, for example, exhaust steam from a turbine, or by a vapor previously produced in a still, which is condensed on the other side of the heat transfer wall. The rate at which the distilland is evaporated from a given area of the heat transfer surface is dependent on the rate at which heat is transferred to the distilland, normally measured in terms of B.t.u.'s/hr. sq. ft. This heat transfer rate is dependent on the overall thermal resistance presented by the heat transfer wall itself, together with that of the layer of distilland on one side and the layer of condensate on the other. Every material has a certain resistance to heat transfer and this resistance multiplied by the thickness of the material can be used to calculate the thermal resistance of a particular layer or the combined thermal resistance of multiple layers.

The thermal resistance of water is quite high, while that of materials from which a heat transfer wall is normally made, for example copper, is relatively low. Other variables being constant, the way to maximize the heat transfer rate is to keep the layers of distilland and condensate as thin as possible over the whole area of the heat transfer surface, with this limitation; namely, that no part of the surface on the distilland side becomes dry.

The advantages of a high heat transfer rate are that the size of the still to produce a given quantity of fresh water of a desired degree of purity from saline water in a given time is minimized. The investment in plant to produce the water is, therefore, less, so that the use of high heat transfer rate distillation apparatus will tend to reduce the cost of the fresh water produced. Ultimately, whether fresh water will be produced from saline water depends on the cost of the water so produced. Any reduction in cost will increase the competitive position of fresh water produced from saline water.

One method of achieving a thin water layer on the surface where the steam condenses it to utilize a special surface construction in which parallel grooves of a

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specific design and on the order of thousandths of an inch deep are milled in the metal forming the surface. In use, the steam initially condenses on the entire condensing surface. That condensate, which forms on the crests between the grooves, flows into the grooves, due to surface tension, forming a heavy layer of water there, but at the same time substantially exposing the crests directly to steam. As a result, the effective or average thickness of condensate on the surface is quite small. The heat transfer rates for this configuration appear to be very high on the crests, which have only a very thin film of condensate upon them, resulting in a high average heat transfer rate for the whole surface.

The disclosure of such a special surface construction has been accompanied by mathematical derivations which show the need for the particular configurations and dimensions in order to achieve the maximum efficiency in condensing steam; see for example, *Zeitschrift fuer Angewandte Mathematik und Physik*, vol. 5, 1954, pages 36 to 49, by R. Gregorig.

The surface described in the above reference is designed for use in condensing steam, and is not particularly suitable for use in evaporating saline water since the small grooves are quite easily clogged by the formation of scale. The formation of scale occurs when the distilland in a particular surface area is completely evaporated, leaving the salts which were previously in solution as a deposit on the surface. This result is avoided, if possible, by not entirely evaporating the distilland; however, over a period of time, perhaps due to slight variations in the distilland feed rate, some scale may be formed.

The endeavor to achieve a thin film of saline water on the evaporating surface of distillation apparatus has been met in one prior art device by rotating wiper blades which continuously distribute the distilland over the interior of a cylindrical member while at the same time maintaining the distilland in a thin film. This apparatus produces a low thermal resistance for the water layer on the evaporating side of the heat transfer wall.

The combination of this wiped film evaporating surface and the finely grooved condensing surface described above results in a heat transfer wall having a high heat transfer rates, since the average thickness of the films on both the evaporating and condensing surfaces is quite small. Nevertheless, two problems, inherent in obtaining high heat transfer rates in this way, exist. These are the expense of manufacturing the condensing surface due to the precision with which the grooves for this surface are made, and the costs associated with utilizing moving parts on the evaporating surface; namely, the initial cost of the mechanism for rotating the wiper blades, the increased operating cost due to the maintenance and replacement of moving parts due to wear, and the cost of the power to drive the wipers.

It is, therefore, an object of this invention to provide a heat transfer wall suitable for use with saline water distillation apparatus which has a high heat transfer rate.

It is also an object of this invention to provide such a heat transfer wall which can be economically manufactured.

It is a further object of this invention to provide a heat transfer wall which will achieve high heat transfer rates without moving parts.

In a preferred form of the invention, evaporating and condensing surfaces are constructed on opposite sides of a heat transfer wall which may be used in distillation apparatus. The configuration of these surfaces is generally a series of elongated parallel protuberances or convolutions. These protuberances or convolutions are of such dimensions that they can easily be formed by using a die, rolling or extrusion. In use, the saline water or distilland is delivered to the evaporating surface near its

top so that it will run down the surface between the protuberances under the influence of gravity. The amount of distilland supplied does not completely fill the area between the protuberances. The heat transferred through the wall from the condensing surface causes the distilland to boil which splashes the distilland over the surfaces of the protuberances. The wall is constructed of a material which the distilland wets or adheres to, but at the same time, the surface tension of the distilland tends to pull any excess distilland into the depressions between the protuberances. The overall effect is that the distilland spreads in a very thin film over the surfaces of the protuberances. This film is continuously replenished, as it evaporates, by more distilland splashing from the grooves.

The length of the wall and the rate at which the distilland is supplied are chosen so that no precipitation of salts occurs from the distilland.

The vapor evolved from the evaporating surface is thereafter exposed to a condensing surface of another similarly constructed heat transfer wall positioned in the vicinity of the evolved vapors. If desired, the vapor may be condensed on the opposite or condensing side of the same heat transfer wall, provided a sufficient elevation in pressure is first given the vapor.

The condensing surface of the heat transfer wall is cooled, by the transfer of heat to the distilland, below the vaporization temperature of water at the pressure involved, so that the vapor condenses on this surface. This condensed vapor or distillate flows from the crests of the protuberances into the adjacent grooves under the influence of gravity and surface tension and is collected at the bottom of the wall. The thickness of the condensate layer on the protuberances is, therefore, kept very thin so that the heat transfer rate is maximized.

The invention will be better understood from the following description taken in connection with the accompanying drawing, in which:

FIGURE 1 is a schematic isometric of a portion of a heat transfer wall in accordance with one embodiment of the invention;

FIGURE 2 is a schematic plan, in a cross-section of a wall having a heat transfer surface in accordance with the invention;

FIGURE 3 is a schematic elevation of a distillation apparatus incorporating the heat transfer wall of this invention; and

FIGURE 4 is a schematic elevation of a modified form of a portion of the apparatus of FIGURE 3.

A heat transfer wall in accordance with the invention will now be described with reference to FIGURE 1. Heat transfer wall 10 is of a generally corrugated appearance so that both of the surfaces are provided with a plurality of protuberances 12 separated by depressions 14. One surface of wall 10, for example surface 16, may be utilized as an evaporating surface while the opposite surface 18 is operated as a condensing surface.

Evaporating surface 16 can be effectively used by applying distilland near the upper end of this surface so that it flows downwardly under the influence of gravity. When surface 16 is properly designed and constructed, it is found that the distilland does not flow evenly over the entire surface, but instead collects in depressions 14, leaving only a thin film of distilland on protuberances 12.

Sufficient heat is supplied to the condensing surface 18 of heat transfer wall 10 to raise the temperature of the distilland to the point where boiling occurs in depressions 14 as shown in FIGURE 2. Initially, the collected distilland is flowing down depressions 14 as shown at A in FIGURE 2. Steam bubbles form as shown at B. These bubbles burst as at C, splashing the distilland over the adjacent protuberances 12 in a thin film. This boiling action continually occurs, in a random manner, in the depressions 14 over the entire evaporating surface 16. Ex-

periments seem to show that the maximum rate of evaporation is achieved on protuberances 12 due to the thin film of distilland on this portion of the surface. The boiling which occurs in depressions 14 indicates that heat is transferred to this portion of evaporating surface 16 as well.

Considering condensing surface 18, it is observed that the condensate tends to collect in depressions 14, thereby continually exposing protuberances 12 to new steam or vapor and keeping the overall thermal resistance of the condensing surface low.

The condensate flows down depressions 14 under the influence of gravity so that it may be conveniently collected at the bottom of the wall.

With reference to FIGURE 3, a simplified saline water distillation apparatus in which the heat transfer wall of this invention may be used is illustrated and described. A chamber 20 is provided with heat transfer walls 22 and 24 constructed in accordance with the invention as illustrated in FIGURE 1, to divide the chamber into three compartments 26, 28 and 30. In compartment 26, steam from any source such as a boiler, exhaust steam from a turbine, etc. is admitted through inlet pipe 32 so that the left or condensing surface of heat transfer wall 22 is heated to a temperature t_1 . Due to the transfer of heat from the steam to wall 22, steam condenses on this surface and the condensate flows into the grooves down the condensing surface of the wall in the manner previously described. Outlet pipe 34 is provided to remove this condensate from compartment 26.

Saline water or distilland is admitted to compartment 28 through inlet pipe 36. Deflector 38 is provided to distribute this distilland substantially evenly over the width of the right or evaporating surface of heat transfer wall 22 at or near the top of this surface. As illustrated in FIGURE 4, in lieu of deflector 38, tube 39 having perforations along its length has been used to spray distilland on the evaporating surface. The distilland is preferably provided at a rate which fills the depressions of the evaporating surface without overflowing the crests of the protuberances so that the full advantages of this invention are realized. The distilland is admitted to compartment 28 at a temperature t_2 lower than temperature t_1 on the opposite side of wall 22. Heat is transferred through wall 22 to the distilland due to the temperature difference. Some distilland evaporates while any excess flows down wall 22 and is discharged through outlet pipe 40 as a concentrated salt solution or brine. About 75 percent of the distilland supplied can be safely evaporated without causing the precipitation of the salts in the brine. The vapors which are produced by the evaporation of the distilland fill compartment 28. Some of these vapors impinge on the left or condensing surface of heat transfer wall 24. Due to the transfer of heat from these vapors to wall 24, they condense, producing distillate which flows down the condensing surface of the wall. Outlet pipe 42 is provided to remove this distillate (now fresh water) from compartment 28. Barrier 44 prevents mixing of the distillate with the excess distilland. The vapors which condense on the condensing surface of heat transfer wall 24 raise the temperature of this surface to a temperature t_3 . The right surface of this wall is cooled to a temperature t_4 lower than temperature t_3 within chamber 28 by cool saline water which is admitted to compartment 30 through inlet pipe 46 and spread across the right surface of heat transfer wall 24 by deflector 48. Tube 49, illustrated in FIGURE 4, may be substituted for deflector 48. The cool saline water is elevated in temperature during its passage down this surface and discharged through outlet pipe 50. This heated saline water may be the supply for inlet pipe 36.

Certain sizes and proportions of heat transfer wall 10 of FIGURE 1 should be utilized in order to best realize the advantages of this invention. Referring again to FIGURE 1, H represents the height of the protuberance from

base to peak or the depth of the depression; P represents the pitch, or distance between similar points on adjacent protuberances; T represents the thickness of the heat transfer wall; and L represents the length of the wall.

In a particular embodiment of the invention, a copper sheet of thickness (T) of about 0.040 inch was corrugated to yield a height (H) of about 0.062 inch and a pitch (P) of about 0.125 inch. An average temperature difference between condensing surface 18 and evaporating surface 16 over the length (L) of the wall of 10° F. was maintained with L made about 54 inches.

More generally, height (H) may be from 0.025 to 0.250 inch, and pitch (P) may be from 0.050 to 0.500 inch. Thickness (T) as in any heat transfer wall should be minimized. When a particular thickness has been chosen, an appropriate height and pitch can be determined by the following approximate relationships:

$$\begin{aligned} H &= 2T \\ P &= 4T \end{aligned}$$

In addition, length (L) may be selected in accordance with the dimensions of height (H) in a ratio of from 50:1 to 5000:1. The particular length selected is determined by the operating condition of the distillation apparatus in which the wall is to be used. Since the evaporating heat transfer surface 16 only operates as described when the distilland collects in depressions 14 leaving the crests of protuberances 12 with only a thin film, distilland should be applied to the upper end of surface 16 at a rate which achieves this. In addition, it can be seen that as the distilland progresses downward, more and more will be evaporated and eventually surface 16 could become completely dry. This result is undesirable since the salts form on the surface as scale. Evaporation occurs at a rate which increases as the temperature difference between condensing surface 18 and evaporating surface 16 increases provided the pressures associated with these processes are not varied. Where this temperature difference is high, the length of the wall may be shorter; while as the temperature difference decreases, the length may be increased. The length of the wall should not be increased to the point where the distillate upon the condensing surface completely fills the depressions so that the protuberances cannot be drained and exposed to new vapors.

Although distillation, per se, has been performed for years, the process has not heretofore been used to distill saline water on more than a limited basis. One important consideration has been cost. Probably the primary cost factors to be considered are the initial cost of the apparatus and the cost of operating the apparatus when it has been installed. This invention provides a significant reduction in both of these costs. Sheet copper, which is readily available and easily to work, transfers heat at a higher rate than most materials. By using a simple die or roller arrangement, a copper sheet can be corrugated to the configuration of this invention without requiring an expensive milling operation. This result is possible because the dimensions desired are not exceedingly fine nor do they need to be exactly maintained. For the same reason, the wearing of the die used to form the wall need not necessitate immediate replacement as long as the dimensions of the wall fall within the specified ranges.

The cost of operating any apparatus which is designed to transfer heat from one medium to another is decreased if the rate of heat transfer (Q) can be increased. This rate can be illustrated by the formula for the case of heat conduction through a wall as follows:

$$Q = \frac{t_1 - t_2}{R_w}$$

$$\text{B.t.u./hr. ft.}^2 = \frac{(\text{F. deg.})}{(\text{F. deg. hr. ft.}^2/\text{B.t.u.})}$$

The factor $(t_1 - t_2)$ represents the difference between the temperatures on the opposite sides of the wall, while R_w represents the resistance to heat flow of the wall. It is evident that decreasing R_w increases Q, the heat transfer rate. Since both evaporation and condensation occur on the surfaces of whatever thicknesses of liquid may be present on the wall, it is necessary for the heat to be transferred from the surface of the condensing liquid through this layer of liquid to the wall. The heat, after then passing through the wall, passes through the layer of distilland to the surface of this liquid where the surface molecules evaporate.

In the foregoing situation, the formula to be used is modified as follows:

$$Q = \frac{(t_1 - t_2)}{R_o + R_w + R_e}$$

where R_o and R_e represent the individual resistances of the liquid condensing layer and liquid evaporating layer respectively.

An appreciation of the effect these liquid layers have upon heat transfer rate will be realized when a comparison is made between the heat transfer rate for a copper wall alone and for a wall with the addition of two $\frac{1}{16}$ -inch water layers. For a ten-degree temperature difference (Fahrenheit), and a $\frac{1}{32}$ -inch copper wall, Q equals 8.57×10^5 B.t.u./hr. ft.². With the addition of the $\frac{1}{16}$ -inch water layers, Q equals only 3.62×10^2 B.t.u./hr. ft.². In other words, the heat transfer rate for the copper wall alone is over 2000 times greater than the wall with the water layers.

In the wall constructed in accordance with the invention previously described, measurements indicate that a heat transfer rate of 3.30×10^4 B.t.u./hr. ft.² was achieved. It can be seen that an increase of the heat transfer rate almost 100 times over that with $\frac{1}{16}$ -inch water layers is achieved.

While the forming of the heat transfer wall of this invention is preferably accomplished by corrugating a thin metal sheet, in some cases it may be desirable to use a heavier gage stock and to form the protuberances by some other method. In such cases, the protuberance of one surface need not also be the depression of the other surface. In addition, it should be clear that the evaporating and condensing surfaces of this invention can be used individually.

While a particular embodiment of a heat transfer wall has been shown and described, it will be obvious that changes and modifications can be made without departing from the spirit of the invention and the scope of the appended claims.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a heat transfer wall for water distillation apparatus having on one side an evaporating surface and on the other side a condensing surface,

the improvement comprising:

a plurality of elongated protuberances separated by depressions on said evaporating surface, said protuberances being substantially parallel and having

- (1) a pitch P of from 0.050 inch to 0.500 inch,
- (2) a height H of from 0.025 inch to 0.250 inch, and
- (3) wherein the ratio P/H is approximately 2:1 throughout the range of dimensions of said pitch and height

said wall having a length L which compares to height (H) in a ratio of from 50:1 to 5000:1.

2. A heat transfer wall for water distillation apparatus comprising:

a corrugated copper sheet having a thickness T of from 0.025 inch to 0.125 inch;

the corrugations on said sheet providing an evaporating

surface on one side of said wall and a condensing surface on the other side thereof, said surfaces consisting of a plurality of elongated protuberances separated by depressions,

said protuberances being substantially parallel and having a pitch P measured between successive protuberances and a height H measured from the crest of said protuberances to the depths of said depressions, and having a relationship to said thickness T such that

- (1) pitch $P=4T$, and
- (2) height $H=2T$, thereby to maximize the heat transfer rate of said wall,

said wall having a length L which compares to height H in a ratio of 50:1 to 5000:1.

3. In a heat transfer wall for water distillation apparatus having on one side an evaporating surface and on the other side a condensing surface,

the improvement comprising:

a plurality of elongated protuberances separated by depressions on said evaporating surface, said protuberances being substantially parallel and having

- (1) a pitch P of from 0.050 inch to 0.500 inch,
- (2) a height H of from 0.025 inch to 0.250 inch, and
- (3) wherein the ratio P/H is approximately 2:1 throughout the range of dimensions of said pitch and height

a plurality of elongated protuberances separated by depressions on said condensing surface, said protuberances being substantially parallel and having

- (1) a pitch P of from 0.050 inch to 0.500 inch,
- (2) a height H of from 0.025 inch to 0.250 inch, and
- (3) wherein the ratio P/H is approximately 2:1 throughout the range of dimensions of said pitch and height

said wall having a length L which compares to height H in a ratio of from 50:1 to 5000:1.

4. The combination, in a distillation apparatus, of: at least one substantially vertical chamber having a wall comprised of a thin sheet of material having high thermal conductivity,

said sheet being formed into parallel convolutions comprising closely spaced parallel depressions separated by crests between said depressions on both surfaces of the sheet,

the crests on one surface of said sheet forming the depressions on the other surfaces thereof,

said crests and depressions extending vertically down the respective surfaces of said wall;

means to distribute distilland evenly over the upper portion of one surface of said wall whereby said distilland drains downward through the depressions,

said sheet having a thickness T in the range of approximately 0.025 inch to 0.125 inch, the crests and depressions of said convolutions having, respectively, a pitch P measured between successive crests and a height H measured from the crests to the depths of said depressions such that

- (1) $P=4T$, and
- (2) $H=2T$, and

said wall having a length L which compares to height H in a ratio range of approximately 50:1 to 5000:1, thereby to cause the distilland to be attracted from the crests to the depressions by surface tension;

means to apply vapor to the other surface of said

wall to produce condensation thereon to heat said wall and to cause said distilland to boil in the depressions on said one surface producing vapor bubbles therein, which break spreading distilland from the depressions thinly over the crests thereby increasing production of vapor from the crests and cooling said crests to increase condensation on said other side,

said condensation being attracted to the depressions on said other side by surface tension and flowing down said depressions, whereby increased condensation occurs at the crest on said other side and whereby said convolutions increase both vaporization on one side and condensation on the other.

5. The combination, in a distillation apparatus, of: a chamber having a side wall comprised of material of high thermal conductivity, the inner surface of said sidewall being convoluted to provide a plurality of closely spaced parallel depressions separated by crests between said depressions, said crests and depressions extending in a substantially vertical direction down the inner surface of said sidewall;

means to distribute distilland evenly over the upper portion of said surface whereby and distilland drains downward through the depressions;

the convolutions of said inner surface having a pitch P measured between successive crests and a height H measured from said crests to the depths of said depressions wherein

(1) P ranges from approximately 0.050 inch to 0.500 inch,

(2) H ranges from approximately 0.025 inch to 0.250 inch, and

(3) the ratio P/H is approximately 2:1 throughout the ranges of said pitch and said height,

said sidewall have a length L which comprises to H in a ratio range of approximately 50:1 to 5000:1, thereby to cause said distilland to be attracted from the crests to the depressions by surface tension;

means to apply heat to the external surface of said sidewall sufficient to cause said distilland to boil in the depressions producing vapor bubbles therein which break spreading distilland from the depressions thinly over the crests thereby increasing production of vapor from the crests and eliminating dry areas; and

means to condense said vapor on another internal surface of the chamber and to collect distillate draining vertically downward of said other surface.

6. In a distillation apparatus:

a vaporization chamber having two broadside substantially vertical walls of high heat conductive material;

means to heat the exterior surface of one of said walls and to cool the exterior surface of the other wall;

means to distribute distilland to the upper portion of the interior surface of said one wall in a thin layer for vaporization due to heat transferred therethrough, whereby the vapor formed at said one wall condenses on the inner surface of said other wall due to said cooling of its exterior surface;

both of said walls comprising parallel convolutions extending lengthwise of said exterior and interior surfaces thereof,

said convolutions providing spaced parallel crests separated by depressions, the depressions on one side of each of said walls forming the crests on the other side thereof,

the convolutions of said walls having a pitch P measured between successive crests, a height H measured from the crests to the depths of said depressions, and a thickness T of from approximately 0.025 inch to 0.125 inch, and wherein the ratio P/H is approximately 2:1 so that liquid on the crests is attracted to

the depressions by surface tension whereby said depressions provide drainage down said interior surfaces leaving said interior crests with thin films of liquid thereby increasing heat transfer through said walls and increasing distillation.

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7. In a distillation apparatus:

a vaporization chamber having two broadside substantially vertical walls of high heat conductive material;

means to heat the exterior surface of one of said walls and to cool the exterior surface of the other wall;

means to distribute distilland to the upper portion of the interior surface of said one wall in a thin layer for vaporization due to heat transferred therethrough, whereby the vapor formed condenses on the inner surface of said other wall due to said cooling of its exterior surface;

both of said walls comprising parallel convolutions extending lengthwise of said exterior and interior surfaces thereof,

said convolutions providing spaced parallel crests separated by depressions,

the convolutions of said walls having a pitch P measured between successive crests, a height H measured from the crests to the depths of said depressions, and a thickness T of from approximately 0.025 inch to 0.125 inch, said wall having a length L which compares to H in a ratio range of approximately 50:1 to 5000:1, whereby in operation liquid on the crests

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is attracted to the depressions by surface tension whereby said depressions provide drainage down said surfaces leaving the crests with thin films of liquid for increased vaporization on said one surface and increased condensation at the other of said surfaces.

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